

# Low Airspeed Alerting Task

## Appendix 1

### Descriptive Information for Selected Low Speed Awareness, Low Speed Alerting, And Low Energy Alerting Systems

1. Boeing Low Speed Alerting System
2. Falcon 7X EASy Low Speed Alerting and Protection System
3. Airbus Low Energy Awareness Protection General Comments
4. Airbus FCOM – Low Energy Alert and Alpha Floor
5. Bombardier General Comments
6. CRJ-200 FCOM
7. CRJ-700 and 900 FCOM
8. DHC-8 Q400
9. Gulfstream G450/G550
10. Cessna 750 CX with HWI P2000
11. Cessna 560 XLS equipped with HWI P1000
12. Cessna 560 XLS+ equipped with Collins Pro Line 21
13. Cessna 680 Sovereign equipped with HWI Primus EPIC
14. Cessna Legacy Models 560 Ultra, 560 Encore, 560XL with P1000
15. Fokker 100 Flight Envelope Protection (from AOM)
16. Mitsubishi MRJ Low Speed Alert Function

Boeing Basic Implementation of Low Speed Alert			
Alert Trigger Point	Visual Flight Deck Effects	Aural Flight Deck Effects	Inhibits
When the airspeed is 30% or more in the amber band	<ul style="list-style-type: none"><li>- Amber band always present</li><li>- Speed Box <b>steady amber</b></li><li>- EICAS Message-AIRSPEED LOW</li><li>- Master Caution Light</li></ul>	Caution Beeper	TakeOff - until in-air AND [next flap retraction OR valid Vref].  Autoland - < 200 ft; EICAS message is displayed but caution beeper and master caution light are inhibited



THE EXPORT CONTROL VALUE OF THIS OBJECT IS ECCN VALUE 9E991 AND HAS BEEN MARKED COM FOR PURPOSES OF EAR ACCESS CONTROL.

Autothrottle Minimum Speed Operations



FBW Min Speed and Stall Protection



# Falcon 7X EASy Low speed awareness and protection system

## High level description

The Falcon 7X contains a lot of features contributing to crew low speed awareness and low speed protection. These features are mainly implemented within the following systems of the aircraft :

- Cockpit displays and alerting system
- Automatic Flight Control System (AFCS)
- Digital Flight Control System (DFCS)
- 

### 1- Cockpit displays and alerting system :

The following indications or alerts are implemented in the Falcon 7X EASy cockpit :

- Low speed cues (LSC), displayed on the speed tape and composed of three elements :
  - An amber band, indicating the area where airspeed is significantly ( $\approx 5$ kt) below the minimum operational speeds
  - An amber/black band, indicating the area where the Autopilot will be disengaged
  - A red band, indicating the minimum speed which can be achieved with the sidestick on its aft stop (corresponding to the maximum AOA allowed by the DFCS)

The low speed cues are computed based on aircraft weight, altitude, AOA, slats, flaps and airbrakes configuration in order to provide relevant information to the crew in a large variety of conditions (including FCS failures modes). In addition, some specific settings are used in icing conditions (anti-ice on)

- Aural warning “Increase speed !”. This aural sounds as soon as airspeed penetrates the amber band or the AFCS speed protection modes are activated (see below).
- Stall warning : aural “Stall !”. The stall warning is triggered at an AOA that is slightly greater than the maximum allowed by the DFCS. As a consequence, when stall warning sounds the speed is always in the red band. Some specific settings are used in icing conditions (anti-ice on)
- Acceleration chevrons, displayed on the ADI relative to the speed vector
- AOA path limit symbol, indicating the margin between current AOA and stall AOA when in low speed conditions.
- Speed trend, displayed on the speed tape

## 2- Automatic Flight Control System :

In order to avoid situations where the aircraft would go to low speed conditions with autopilot engaged, two protection modes are implemented within the AFCS of the aircraft :

- Autothrottle speed protection (ASP), that is able to command the engine through the Autothrottle when speed decays below minimum operational speeds
- Pitch speed protection (PSP), that is able to adjust the path of the aircraft when ASP alone is not able to recover the aircraft from low speed

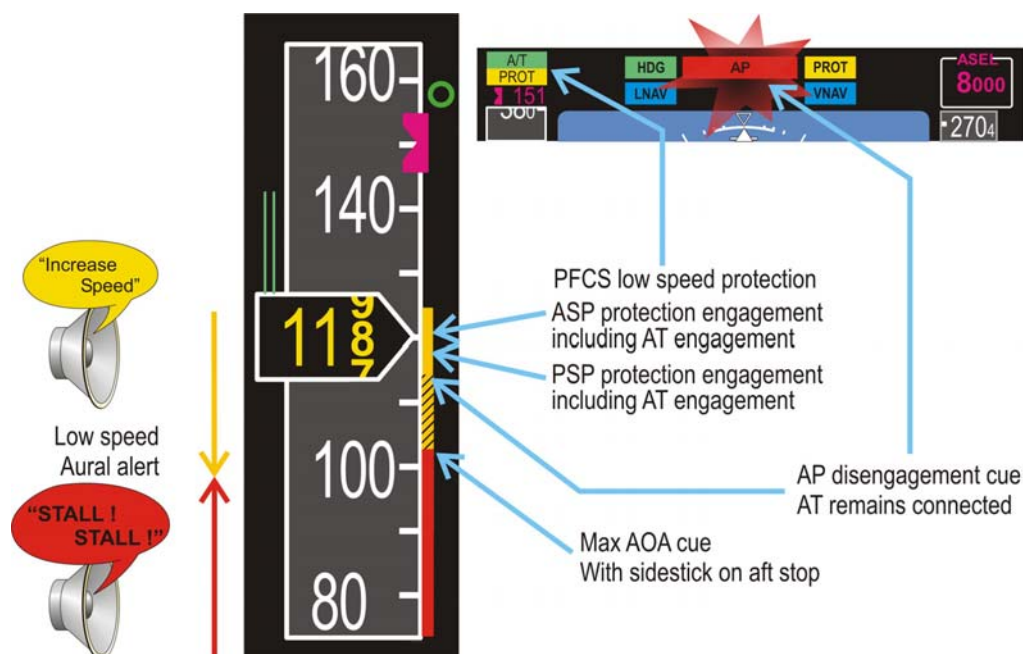
When Autopilot is engaged and controlling the aircraft, if airspeed drops and penetrate in the amber band then ASP will become the active Autothrottle mode and command thrust in order to gain speed and recover a safe nominal value. Note that 1) Autothrottle will automatically engage at ASP activation if not already engaged, and 2) ASP can command throttle up to max Take-off setting if required depending on the encountered conditions.

If airspeed continues to drop in the amber band despite ASP has activated, then PSP will activate and adjust (reduce) aircraft path to help airspeed to increase.

ASP and PSP protection modes have been designed in order to cover a wide range of situations and allow speed recovery before reaching the amber/black or red bands. The design includes some anticipation in the activation of the protection modes based on deceleration rate, meaning that ASP and PSP can activate before the airspeed reaches the top of the amber band in case of high deceleration rates. Note that the aural “Increase speed” will sound and warn the crew as soon as ASP or PSP activate, even if airspeed is still above the top of the amber band.

When ASP and PSP mode are activated, this status is displayed (yellow flashing “PROT” label) in the Flight mode annunciator of the Primary Flight Displays. Activation of ASP and PSP is also annunciated in the HUD.

**Figure 1 : Aural, Speed tape, and Flight Modes Annunciator**



### 3- Digital Flight Control System :

The F7X is fitted with a full authority Digital Flight Control System (DFCS) that has been specially designed to contribute to crew low speed awareness and low speed protection.

- DFCS offers a protection against excessive AOA, either when the pilot is controlling the aircraft manually or when using the AFCS. The protection ensures that the aircraft will not go to stall. With this kind of protection, the speed shall never drop down in the red band and stall warning shall never be emitted (in nominal conditions).
- The DFCS has also been designed in order to ensure that the pilot will immediately recognize that aircraft is in low speed conditions, by restoring a strong static speed stability. This change in aircraft behavior is progressive and can be perceived by the pilot as soon as the airspeed penetrates the amber band, and is increasing as the speed drops down towards stall speed. If airspeed drops down to the amber/black band, the autopilot is disengaged and the DFCS alone performs low speed protection.

# Low Energy awareness protection on Airbus Fly-By-Wire aircraft

Compiled by N. Fabre-Raimbault & C. Thibaudat (Airbus) - FTHWG Sept, 16 2010

## 1) Design

A set of four protections is implemented on all Airbus FBW aircraft to protect the aircraft from low speed and low energy situations. They come in addition to the 'High angle attack' hard protection, protecting the aircraft from aerodynamic stall :

- The **A/THR**, if active in speed mode, prevents the speed to drop below VLS (Lowest Speed Selectable) regardless of target speed
- The **Low-energy alert** triggers a repetitive aural alert "Speed-Speed-Speed" when the angle of attack becomes higher than an angle of attack threshold function of aircraft configuration, deceleration rate, flight path angle. It draws the crew attention to the speedscale and indicates the need to adjust thrust .  
In addition, the speedscale provides with a gradual overview of the different forthcoming critical speed threshold (from VLS in amber to Valphamax in plain red)
- The **Alphafloor**, an A/THR function, sends automatically TOGA thrust when the aircraft angle of attack exceeds the  $\alpha$ -floor threshold in case the pilot has not properly adjusted the thrust. "A.FLOOR" is displayed (on FMA) and speedscale shows black-amber stripes. The goal is to avoid flying at low speed with low thrust.
- The **Windshear** aural warning triggers a message 'Windshear Windshear Windshear' when angle of attack becomes higher than an angle of attack threshold function of aircraft configuration and estimated longitudinal and vertical severity factors of encountered windshear.

The objectives of the low energy alert and of the alphafloor function are to protect the flight path angle by providing means to achieve a proper level of energy. The low energy alert will be triggered during deceleration before the activation of  $\alpha$ -floor.

**(see FCOM pages attached for more information)**

- High angle of attack protection

Moreover, on all Airbus FBW aircraft, a high incidence protection protects the aircraft by limiting the angle of attack to a maximum achievable value  $\alpha$ -max. This is a hard protection and cannot be overridden by the pilot (in normal laws). The high angle of attack protection is an aerodynamic protection.

## 2) Airbus experience

Non overrideable high angle of attack protection is one of the main Electrical Flight Control System features of Airbus aircraft since the A320. It is available whatever the flight conditions.

Low energy alert is available at low altitude only ( below 2000ft or 2500ft depending on the aircraft model) to cover the critical situation when the aircraft is close to the ground.

Because the aircraft remains safe even when the pilot pulls on the stick to the stop thanks to the high angle of attack protection, Airbus position is that no additional alerts about low speed/energy situations is needed at high altitude because large altitude loss due to stall cannot occur on Airbus Fly-By-Wire aircraft.

Moreover, no additional stall warning or stick shaker is needed with this kind of protection. Stall warning is only re-introduced on Airbus aircraft when the angle of attack protection is lost (loss of 'normal laws').

At the beginning of A320 service experience, the setting of the  $\alpha$ -floor function (automatic application of full thrust above a given angle of attack) was reviewed after the A320 Bangalore accident: the accident investigation revealed that the  $\alpha$ -floor function came too late for avoiding the impact with ground.

The  $\alpha$ -floor setting was then decreased to the minimum setting compatible with FAA request and some phase advance terms with speed rate introduced. For remind, FAA considers the  $\alpha$ -floor function as a stall indicator (equivalent to a stall warning for non-protected aircraft) and requires to demonstrate adequate bank manoeuvrability (25.143 compliance) without  $\alpha$ -floor triggering. This pushes to set  $\alpha$ -floor triggering threshold to high incidence.

The lack of static stability between VREF (or the lowest selectable speed called VLS at Airbus) and the starting point of the  $\alpha$ -protection (i.e.  $\alpha$ -prot) was also evoked as a possible contributing factor to the Bangalore accident.

Then Airbus introduced a new function to compensate for this lack of static stability: the "low energy alert", which is described above. It has been later enforced through a new special condition for Airbus aircraft.

### 3) Compliance requirements

Low energy awareness is covered by EASA and FAA requirements through special conditions.

#### **Extract from Statement of Issue**

*Low Energy Awareness: Static longitudinal stability provides awareness to the flight crew of a low energy state (low speed and thrust at low altitude). Recovery from a low energy state may become hazardous when associated with a low altitude(1) and performance limiting conditions.*

*These low energy situations must therefore be avoided, and pilots must be given adequate cues when approaching such situations.*

#### **Background**

*Low Energy Awareness: Past experience on airplanes fitted with a flight control system providing neutral longitudinal stability shows there is insufficient feedback cues to the pilot of excursion below normal operational speeds. The maximum angle of attack protection system limits the airplane angle of attack and prevents stall during normal operating speeds, but this system is not sufficient to prevent stall at low speed excursions below normal operational speeds. Until intervention, there are no stability cues since the aircraft remains trimmed. Additionally, feedback from the pitching moment due to thrust variation is reduced by the flight control laws. Recovery from a low speed excursion may become hazardous when the low speed situation is associated with a low altitude and with the engines at low thrust or with performance limiting conditions.*

**Low energy awareness complies with the following requirements :**



*The airplane should provide adequate awareness cues to the pilot of a low energy (low speed/low thrust/ low height) state to ensure that the airplane retains sufficient energy to recover when flight control laws provide neutral longitudinal stability significantly below the normal operating speeds. This may be accomplished as follows:*

*a) Adequate low speed/low thrust cues at low altitude may be provided by a strong positive static stability force gradient (1 pound per 6 knots applied through the sidestick), or*

*b) The low energy awareness may be provided by an appropriate warning with the following characteristics:*

*(i) It should be unique, unambiguous, and unmistakable.*

*(ii) It should be active at appropriate altitudes and in appropriate configurations (i.e., at low altitude, in the approach and landing configurations).*

*(iii) It should be sufficiently timely to allow recovery to a stabilized flight condition inside the normal flight envelope while maintaining the desired flight path and without entering the flight controls angle-of-attack protection mode.*

*(iv) It should not be triggered during normal operation(2) , including operation in moderate turbulence for recommended maneuvers at recommended speeds*

*(v) It should not be cancelable by the pilot other than by achieving a higher energy state.*

*(vi) There should be an adequate hierarchy among the various warnings so that the pilot is not confused and led to take inappropriate recovery action if multiple warnings occur.*

*c) Global energy awareness and non-nuisance(2) on low energy cues should be evaluated by simulator and flight tests in the whole take-off and landing altitude range for which certification is requested. This would include all relevant combinations of weight, center of gravity position, configuration, airbrakes position, and available thrust, including reduced and derated take-off thrust operations and engine failure cases. A sufficient number of tests should be conducted, allowing the level of energy awareness and the effects of energy management errors to be assessed.*

*Note( 1) : it is recognized that the critical situation to cover is low altitude in case of ground proximity*

*Note (2):FAA interpret non-nuisance requirement in showing compliance to 25.143(h) bank angle maneuverabilities free of alpha floor*



## LOW ENERGY PROTECTION

The objectives of the low energy alert and of the alpha floor function are to protect the flight path angle by providing means to achieve a proper level of energy:

- The low energy alert is the first level of protection. It requires crew action, for manual thrust increase.
- The alpha floor function is the second level of protection. It automatically sets maximum thrust.

For more information: Refer to [Alpha Floor Protection](#).

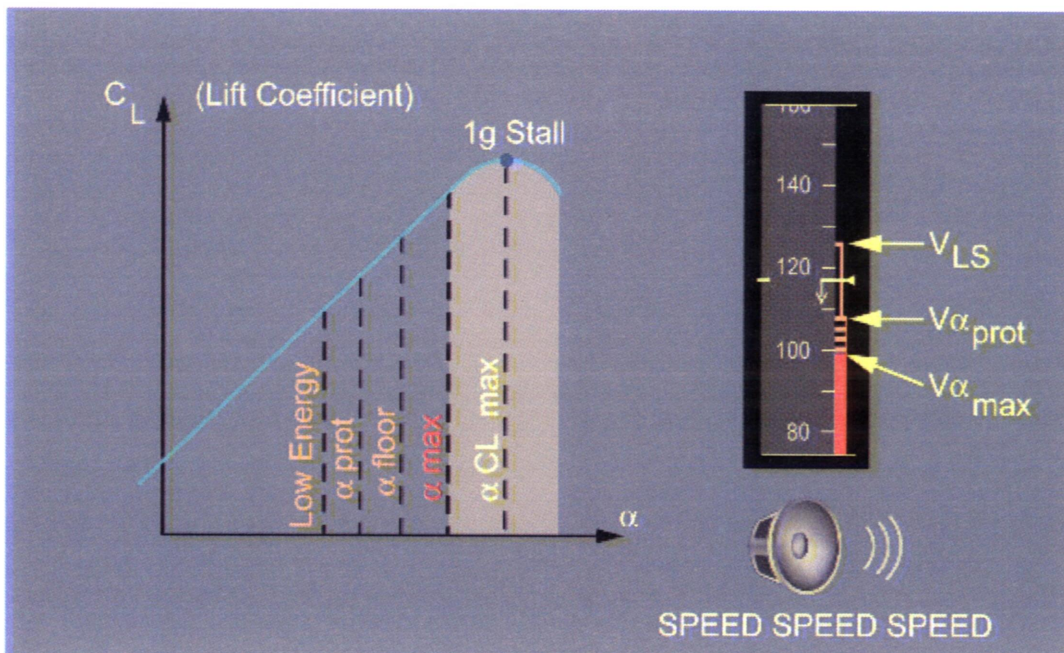
When it is not possible to recover a positive flight path angle using the pitch control, an aural alert "SPEED SPEED SPEED" is repeated every 5 seconds, as long as the thrust has not been sufficiently increased.

### Speed

The low energy alert is triggered when the speed is between VLS and  $V_{\alpha_{prot}}$ .

The low energy alert is triggered when the speed is close to  $V_{\alpha_{prot}}$ , but it can be triggered closer to VLS, in the case of:

- A negative flight path angle, or
- A negative speed trend.



The low energy alert will be triggered during deceleration before the activation of #-floor. The delay between the low energy alert and the activation of #-floor depends on the deceleration rate.

The low energy alert is available:

- Below 2 500 ft RA
- Above 100 ft RA for landing, above 200 ft RA for takeoff
- In CONF 2, 3 and FULL

If the slats or flaps are jammed, the low energy alert is available when the aircraft is not in clean configuration.

- In all flight control laws (Normal, Alternate, and Direct)

It is inhibited when:

- At least one engine thrust lever is at TOGA, or
- #-floor is active, or
- The angle of attack has reduced below the warning threshold.

The low energy alert requires the following equipment

- 1 PRIM
- 1 ADIRS
- 1 RA

// END



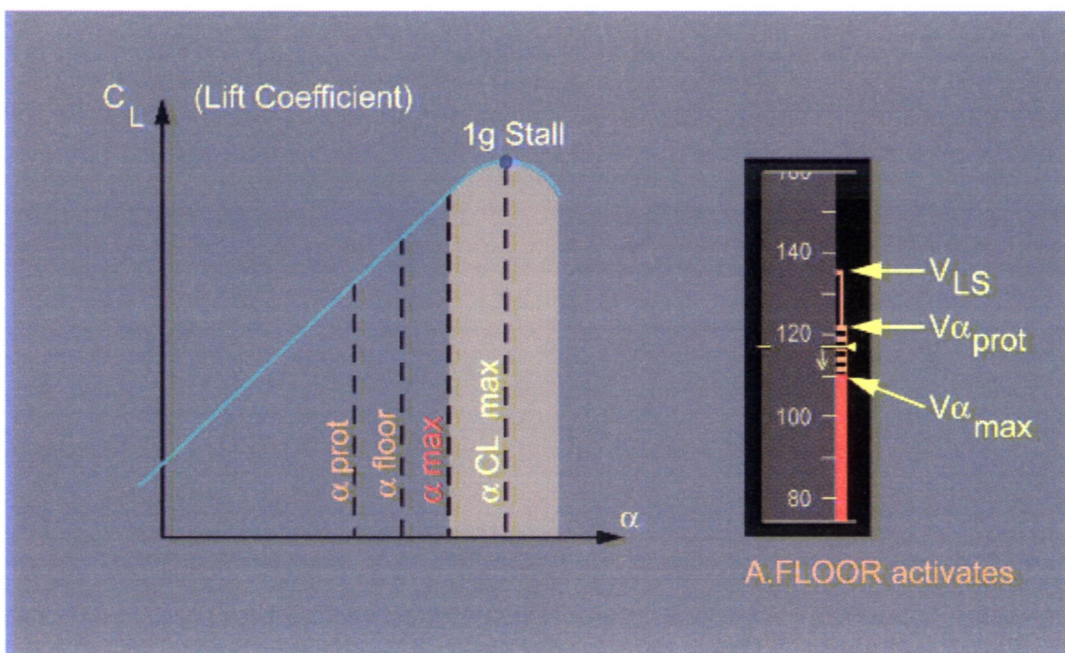
## ALPHA FLOOR PROTECTION

To avoid flying at low speed with a low thrust, the #-floor function automatically applies TOGA thrust, when the angle of attack exceeds the #-floor threshold (between #-prot and #-max). TOGA thrust is applied, whatever the thrust lever position and A/THR engagement status.

If the A/THR was previously not active, it automatically activates. The thrust remains at TOGA, as long as the A/THR is active. (Refer to [A/THR Mode Reversions](#))

The #-floor function activates when one of the following conditions is true:

- The angle of attack is greater than #-floor ( #-floor depends on the aircraft's configuration)
- The angle of attack protection is active, and the sidestick deflection is close to full back stick
- The pitch up attitude protection is active, and the sidestick deflection is close to full back stick



#-floor is available:

- From liftoff down to 100 ft RA
- In normal law.

#-floor is inhibited above M 0.5.

### General comments/Clarifications on CRJ200/700/900 low speed awareness philosophy.

In addition to stall warning provided by stick shakers and stall prevention/identification provided by stick pusher, the functionality of the Low Speed Cue (checkerboard, displayed on all aircraft) and Low Speed Awareness Indicator (“green line”) are described in the FCOMs of the respective aircraft. The Low Speed Awareness Indicator is, described only in the FAA versions of the FCOM.

The following compares the descriptions in the two FCOMs for CRJ-200 and CRJ-900 (CRJ-700 and CRJ-900 can be considered identical for the purposes of this discussion).

CRJ-200 FCOM Vol.1 12-30-14:

#### I. Low Speed Cue

The low speed cue provides an indication of the **speed margin to stick pusher** during normal low speed maneuvers and approaches to stall. The top of the low speed cue corresponds to **1.05 times the computed stick pusher speed**.

#### NOTE

**The minimum speed margin between shaker and pusher is 5%. This is larger in some parts of the flight envelope, particularly higher altitudes where factors other than landing field performance are the prime consideration. Therefore, the stick shaker speeds will be equal to or above the low speed cue.** Respect the stick shaker warning to ensure adequate margin to full stall

A green line is displayed on the PFD speed tape that is **1.26 times the computed stick pusher speed**. The green line is calculated through flap angle, AOA and Mach. The green line is not intended to be used as a substitute for reference speeds, or as a minimum maneuvering speed. It is intended to function as a low speed awareness indicator for the flight crew to inform them that they have a **26% margin above the stick pusher activation speed** that is based on the current flight conditions.

CRJ-900 FCOM Vol.1 34-13-12:

#### (4). Low Speed Cue

The low speed cue provides an indication of the **speed margin to stick shaker** during normal low speed maneuvers and approaches to stall. The top of the low speed cue corresponds to **the onset of the stick shaker**.

#### NOTE

**A high pitch rate at low airspeed may cause the stick shaker airspeed to be higher than that indicated at the top of the low speed cue.** Respect the stick shaker warning to ensure adequate margin to full stall.

A green line displayed on the PFD speed tape that is **1.25 times the stall warning speed marked at the top of the red-black checkerboard on the speed tape**. The green line is calculated through flap angle, AOA and Mach. The green line is not intended to be used as a substitute for reference speeds, or as a minimum maneuvering speed. It is intended to function as a low speed awareness indicator for the flight crew to inform them that they have a **25% margin above the stick shaker activation speed** that is based on the current flight conditions.

There is a difference in the mechanism used to calculate the low speed cue between the two aircraft; although the intent is to provide a comparable end result for the pilot – namely awareness when the aircraft speed is closer than is desirable to stall warning – the text above largely differs in response to this detail of implementation.

For both aircraft the means used to calculate the speed for the display of the Low Speed Cue and the Green Band is called “normalized angle of attack”. The general formula that is used to calculate the value of the speed cues follows:

$$V_{\text{Speed Cue}} = K \times V_{\text{IAS}} \times \sqrt{\alpha_N}$$

where:  $K$  = Constant (dependent on speed cue and aircraft type)  
 $V_{\text{IAS}}$  = Current airspeed  
 $\alpha_N$  = Normalized AOA (dependent on aircraft type)

The computation for the above formula is performed in the PFD using values of  $K$  and  $V_{\text{IAS}}$  provided by the on-side ADC and a value for  $\alpha_N$  provided by the on-side Stall Protection Computer (SPC) channel. The value of  $K$  is dependent upon both the specific aircraft type and also the parameter which is being calculated (Low Speed Cue or Green Line)

The normalized AOA on the CRJ-200 is calculated with reference to the pusher firing angles and therefore the speed cue computations provide an indication of speed margin above pusher activation.

The normalized AOA on the CRJ-700 / 900 is calculated with reference to the shaker firing angles and therefore the speed cue computations provide an indication of speed margin above shaker activation.

The reason for these differences in implementation goes to the difference in the settings for shaker and pusher firing angles between the two aircraft types. For the CRJ-200 the stick pusher is always set to fire prior to the natural stall of the aircraft (and is thus often referred to as a “pre-stall pusher”). For the CRJ-900 (and indeed also the CRJ-700) the pusher actually fires *after* the point of aerodynamic stall for all slats OUT configurations. This is therefore called a “post-stall pusher”.

The normalized AOA calculation inherently assumes that the aircraft lift-curve slope is linear throughout the range of calculation. As the lift-curve becomes non-linear near the natural aerodynamic stall, the upper limit of the normalized AOA range must therefore be below the point of stall.

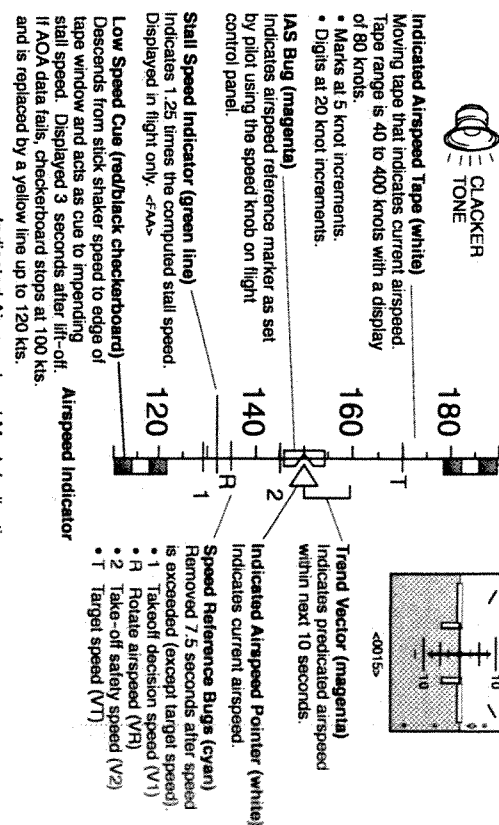
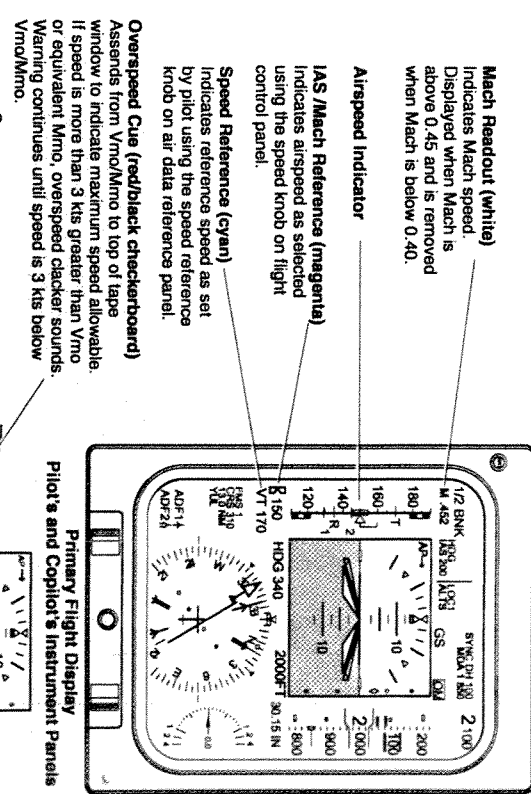
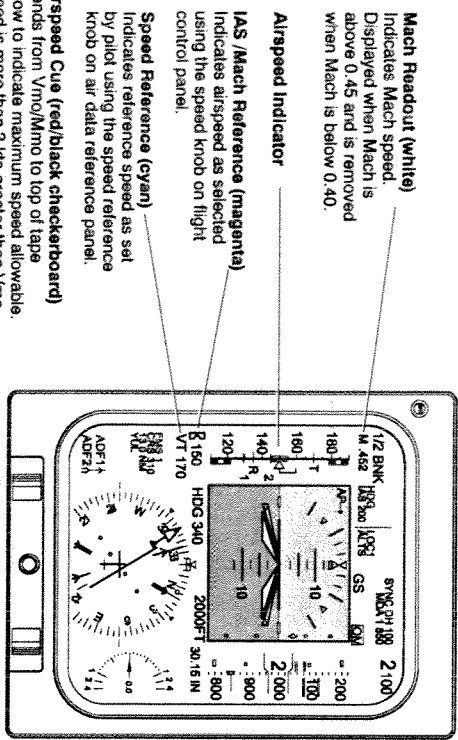


Figure 12-30-5  
Indicated Airspeed and Mach Indicators <MST>

CRJ-200



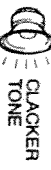
**Mach Readout (white)**  
Indicates Mach speed.  
Displayed when Mach is above 0.45 and is removed when Mach is below 0.40.

**Airspeed Indicator**  
Indicates airspeed as selected using the speed knob on flight control panel.

**IAS /Mach Reference (magenta)**  
Indicates airspeed as set by pilot using the speed reference knob on air data reference panel.

**Speed Reference (cyan)**  
Indicates reference speed as set by pilot using the speed reference knob on air data reference panel.

**Overspeed Cue (red/black checkerboard)**  
Assends from Vmo/Mmo to top of tape window to indicate maximum speed allowable. If speed is more than 3 kts greater than Vmo or equivalent Mmo, overspeed clacker sounds. Warning continues until speed is 3 kts below Vmo/Mmo.

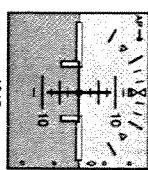


**Indicated Airspeed Tape (white)**  
Moving tape that indicates current airspeed. Tape range is 40 to 400 knots with a display of 80 knots.  
• Marks at 5 knot increments.  
• Digits at 20 knot increments.

**IAS Bug (magenta)**  
Indicates airspeed reference marker as set by pilot using the speed knob on flight control panel.

**Low Speed Awareness Indicator (green line)**  
Indicates 1.3 times the computed stall speed. Displayed in flight only. <FAA>

**Low Speed Cue (red/black checkerboard)**  
Descends from stick shaker speed to edge of tape window and acts as cue to impending stall speed. Displayed 3 seconds after lift-off. If AOA data fails, checkerboard stops at 100 kts. and is replaced by a yellow line up to 120 kts.



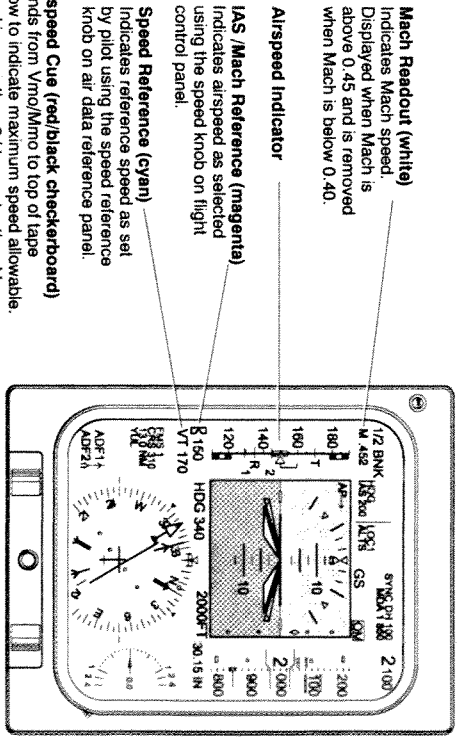
**Trend Vector (magenta)**  
Indicates predicted airspeed within next 10 seconds.

**Indicated Airspeed Pointer (white)**  
Indicates current airspeed.

**Speed Reference Bugs (cyan)**  
Removed 7.5 seconds after speed is exceeded (except target speed).  
• 1 Takeoff decision speed (VT)  
• 2 Take-off safety speed (V2)  
• 1 Target speed (VT)

Indicated Airspeed and Mach Indications <MST>  
Figure 12-30-3

CRJ-700



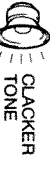
**Mach Readout (white)**  
Indicates Mach speed.  
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**Airspeed Indicator**  
Indicates airspeed as selected using the speed knob on flight control panel.

**IAS /Mach Reference (magenta)**  
Indicates airspeed as set by pilot using the speed reference knob on air data reference panel.

**Speed Reference (cyan)**  
Indicates reference speed as set by pilot using the speed reference knob on air data reference panel.

**Overspeed Cue (red/black checkerboard)**  
Assends from Vmo/Mmo to top of tape window to indicate maximum speed allowable. If speed is more than 3 kts greater than Vmo or equivalent Mmo, overspeed clacker sounds. Warning continues until speed is 3 kts below Vmo/Mmo.

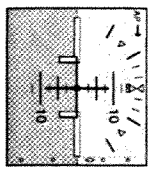


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**Trend Vector (magenta)**  
Indicates predicted airspeed within next 10 seconds.

**Indicated Airspeed Pointer (white)**  
Indicates current airspeed.

**Speed Reference Bugs (cyan)**  
Removed 7.5 seconds after speed is exceeded (except target speed).  
• 1 Takeoff decision speed (VT)  
• 2 Take-off safety speed (V2)  
• 1 Target speed (VT)

Indicated Airspeed and Mach Indications <MST>  
Figure 12-30-5

CRJ-900



DHC-8 Q400  
Low Speed Cue Information

- 1) The Q400 does not have a low speed alerting or low energy alerting system in the same sense that Boeing and Airbus do provide above the stall warning speed. However, because the Q400 is propeller-driven, there is the impact of powered lift.
- 2) The low-speed cue (barber pole) on the Q400 gives the margin to the estimated stall warning speed in the idle power configuration. If the power setting is anything above idle (AEO or OEI), the barber pole will be higher than the actual stall warning speed thus providing some margin to stall warning.
- 3) The low speed cue is a function of idle power stall warning angle-of-attack. There is a basic stall warning AOA that is modified by slightly by flap position, Mach and icing condition. Landing gear position is not considered. Gross weight and cg affect aircraft AOA which will in turn affect the low speed cue.
- 4) Because the low speed cue is based primarily on AOA, load factor is automatically accounted for and the low speed cue increases in maneuvering flight (positive g).
- 5) Stall warning is not modified by deceleration (or alpha dot) and thus the low speed cue is also unaffected. However, there is an airspeed trend vector that provides a 10 sec look-ahead for airspeed which will give the crew an indication of how rapidly they are approaching the low speed cue.
- 6) Regarding icing conditions, stall warning is manually advanced by the pilot selecting an "INCR REF SPD" switch. The stick pusher is not advanced. This in turn increases the low speed cue. Reference speeds are increased in the AFM when the INCR REF SPD switch is selected.
- 7) The ice protection system is manually selected by the pilot based on either a visual assessment by the crew or an ice detector alert.
- 8) The low speed cue is active any time that the airplane is airborne. There are no special considerations for any phase of flight or for manual vs. autoflight.
- 9) Turbulence nuisance effects are minimized through filtering of the low speed cue and stall warning.

I hope that this helps in the upcoming discussions. For the Global Express, the information is very similar to that provided for the CRJ.

Allan Paige

## Gulfstream G450/G550 Low Speed Awareness and Stall Protection System (submitted by S. Taylor and J. O'Meara)

The stall warning and protection system (SWPS) installed on the Gulfstream Model G450/G550 aircraft provides a two stage stall warning/protection. The first stage provides warning to the pilot that the aircraft is approaching a stall condition. This warning is given through a stick shaker motor and low speed awareness indication on the airspeed tape. The second stage or stall protection is a stick pusher actuator that results in a pitch down force applied to the control column prior to aerodynamic stall.

The stall warning function compares the current normalized AOA to an established normalized AOA threshold. The normalized AOA stick shaker threshold used is 0.85. Prior to stick shaker, a red low speed awareness (LSA) bar is located on the inside right edge of the airspeed tape (see Figure 1). It extends from the stick shaker speed to the bottom edge of the airspeed tape. This method of low speed awareness and pitch limit indication is the same for both the classic primary flight display (Figure 1) and the synthetic vision primary flight display (SV PFD) (Figure 2).



**Figure 1. Classic G450/550 Primary Flight Display (PFD) with Low Speed Awareness Bar During Approach**

An additional cue that is provided to alert the crew to an impending stick shaker is the pitch limit indicator, or PLI. The amber PLI consists of two horizontal lines with vertical slanting lines extending upward from the horizontal lines. The PLI is displayed when the normalized AOA is greater than 0.7, and moves vertically along the pitch ladder. The PLI is referenced to the airplane symbol or FPM (Flight Path Marker) depending on the symbology in use as selected by the pilot. The SV PFD provides additional speed cueing with the speed error tape off the left wing of the FPM. The length of the speed error tape represents the difference between the selected airspeed and the current airspeed, same as used on the HUD. The speed error tape rises or descends to a maximum length of approximately 0.63 inches at an airspeed differential of 20 kt/.04M. Downward movement of the speed error tape indicates current airspeed is less than the selected airspeed. Upward movement of the speed error tape indicates current airspeed is greater than the selected airspeed.

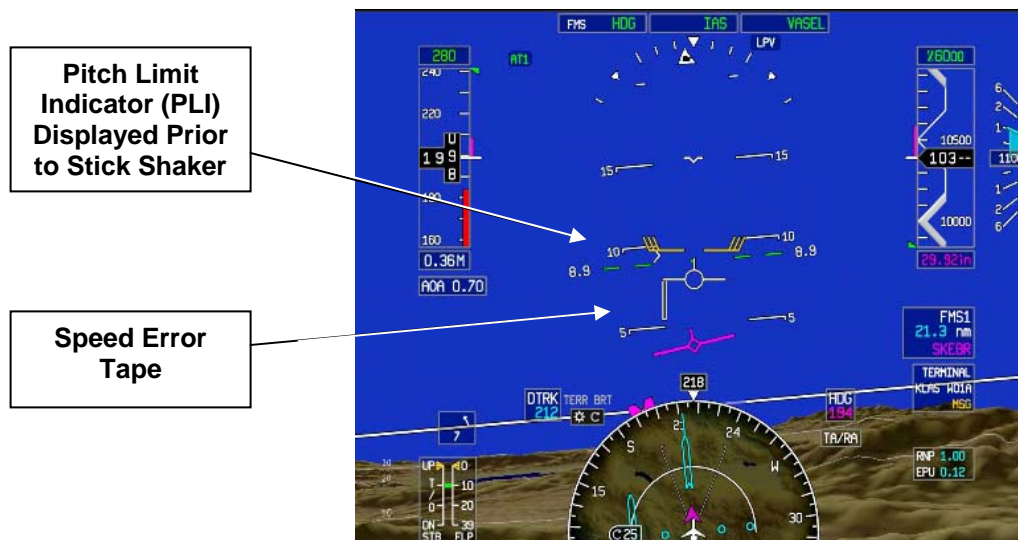


Figure 2. SV PFD with Pitch Limit Indicator

When the airplane deceleration rate as shown by the airspeed trend vector touches the top of the LSA tape, the IAS/mach digital display, airspeed rolling digits, and angle of attack readout will turn amber. When the FPM on the SV PFD (or any selected flight director airplane symbol on the classic PFD) touches the PLI, the stick shaker will activate indicating that the IAS is equal to low speed awareness speed. The IAS/mach digital display, airspeed rolling digits, and angle of attack readout will turn red. Continued deceleration of the airplane into the red zone of the LSA will eventually cause the stick pusher to activate. Examples of this are in Figure 3 and 4 below, which illustrates the changes in airspeed digits and AOA during an approach to stall.



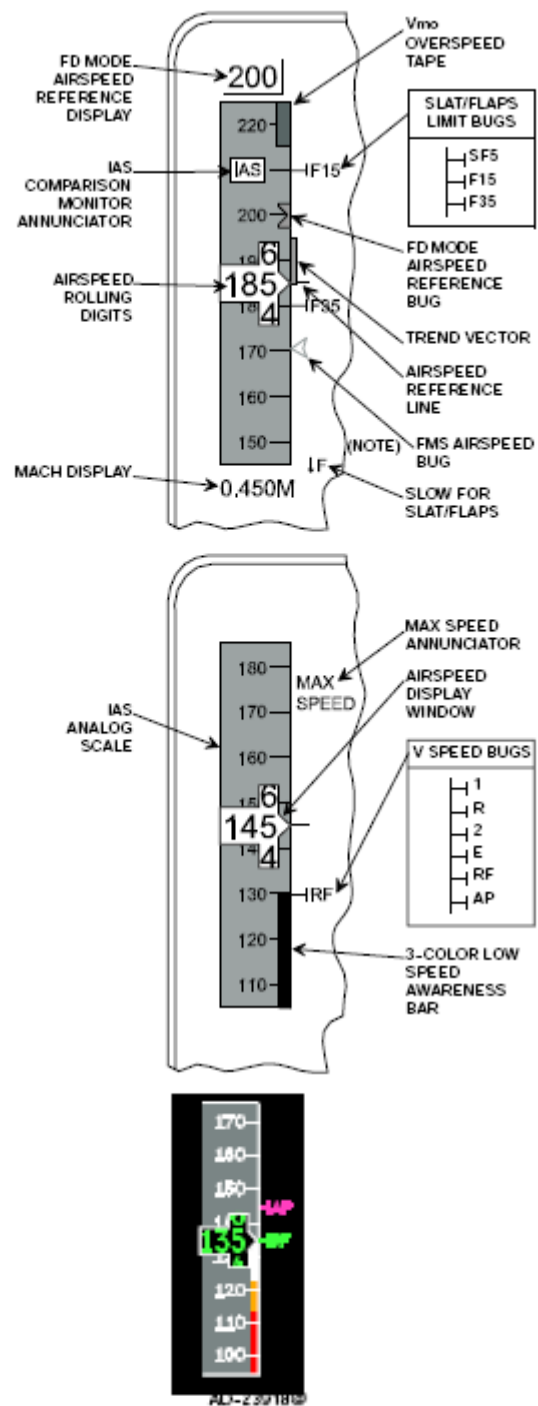
Figure 3. G450/550 Classic Primary Flight Display Demonstrating Amber and Red Airspeed and AOA Limits During an Approach to Stall



**Figure 4. G450/550 SV PFD Demonstrating Amber and Red Airspeed and AOA Limits During an Approach to Stall**

Gulfstream classic aircraft do not have alpha-limiting via flight control laws as they are not fly-by-wire aircraft.

## Cessna Model 750 CX equipped with Honeywell P2000



Low Airspeed Awareness Thermometer

**Cessna Model 560XLS equipped with Honeywell Primus P1000 CDSR**



Low Airspeed Awareness Thermometer

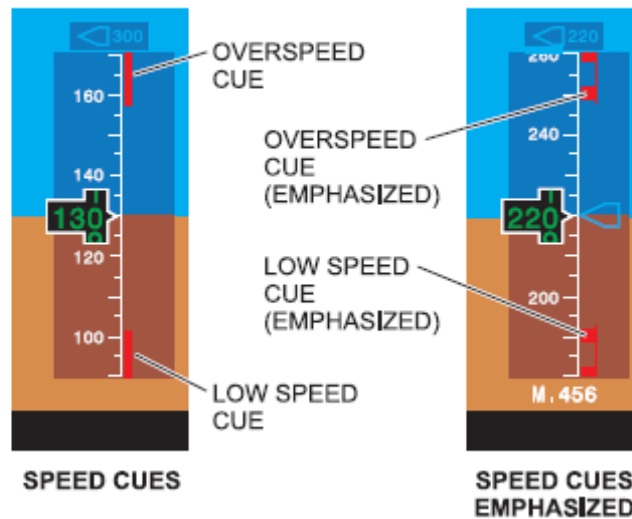


Airspeed Trend Vector



Green caret along the right outside scale identifies 1.3 V<sub>stall</sub>

## Airspeed Awareness



## Airspeed Trend Vector

The airspeed trend vector is a vertical, variable length line that shows to the right of the airspeed scale. The trend vector originates from a gray tick mark directly opposite of the airspeed pointer (current airspeed). The airspeed trend vector approximates what airspeed is in 10 seconds at present rate of acceleration or deceleration. The airspeed trend vector extends up for acceleration, and down for deceleration.

## Impending Stall Speed Cue

An Impending Stall Speed Cue (ISS) shows on the airspeed scale. The cue is based on airspeed and Angle of Attack. The impending stall speed low speed cue is constantly positioned from the bottom of the airspeed scale to the current calculated ISS value. The cue becomes emphasized and the airspeed digital readouts change color to red when airspeed gets significantly below the ISS. The impending stall cue is a red vertical line that extends from the current ISS value to the bottom of the airspeed scale.

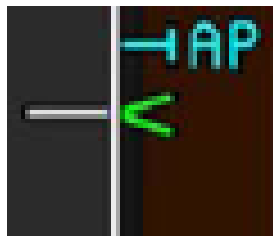
An ISS warning occurs when the current airspeed becomes less than the ISS low speed cue by 2 knots or more, or when the airspeed trend vector goes below the impending stall speed low speed cue by 2 or more knots for 5 seconds or more. The ISS cue changes to a wider red and red outlined dark-blue checker board pattern for a warning condition. The airspeed digital readout changes color to red and flashes for 5 seconds, then shows steady. If the Mach readout is in view, the Mach readout changes color to red and flashes for 5 seconds, then shows steady.



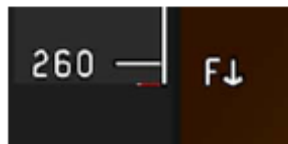
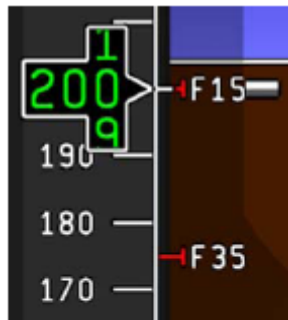
**Cessna Model 680 Sovereign equipped with Honeywell Primus EPIC**



Low Airspeed Awareness Thermometer and Airspeed Trend Vector

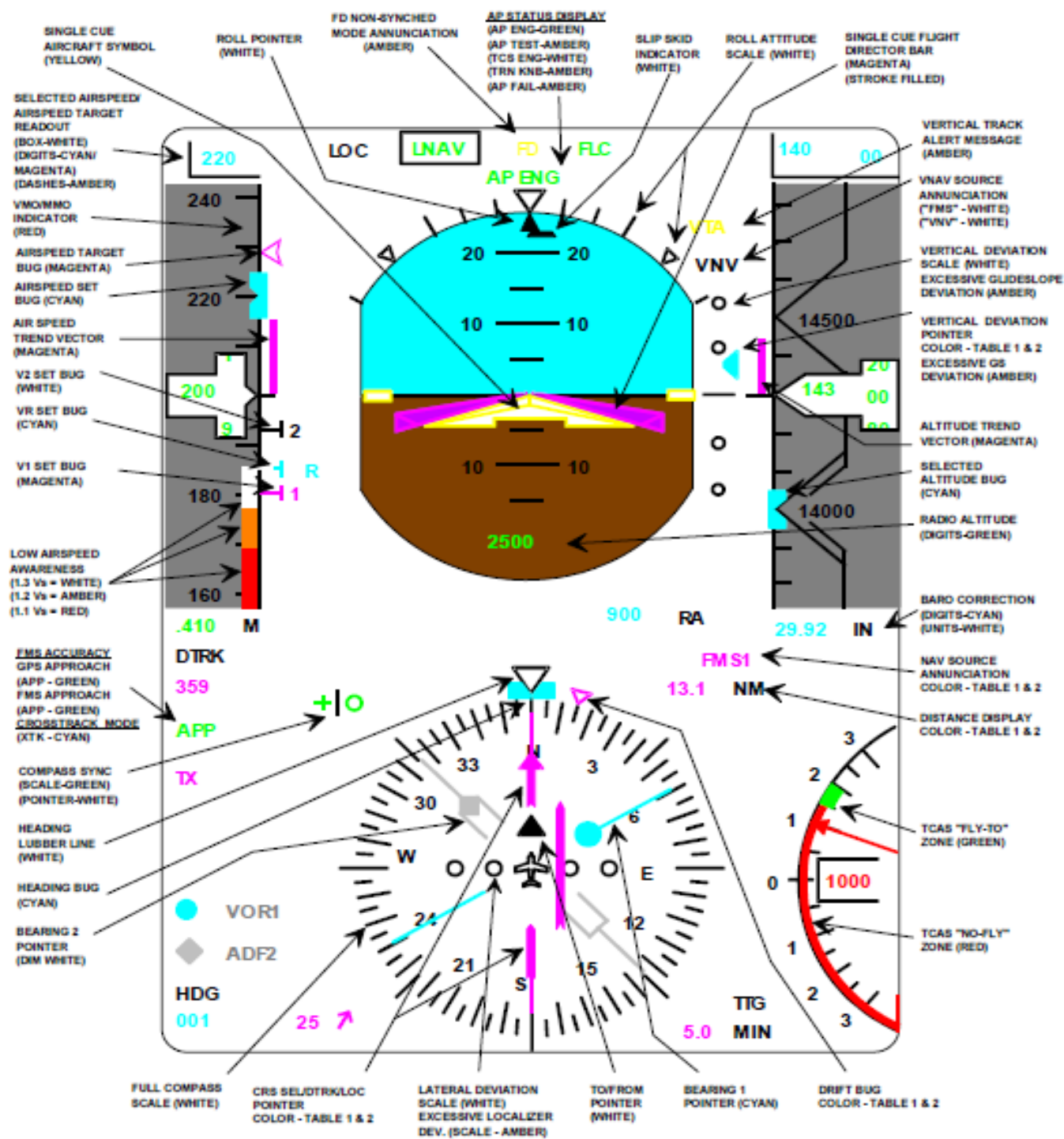


Green caret along the right outside scale identifies 1.3 V<sub>stall</sub>

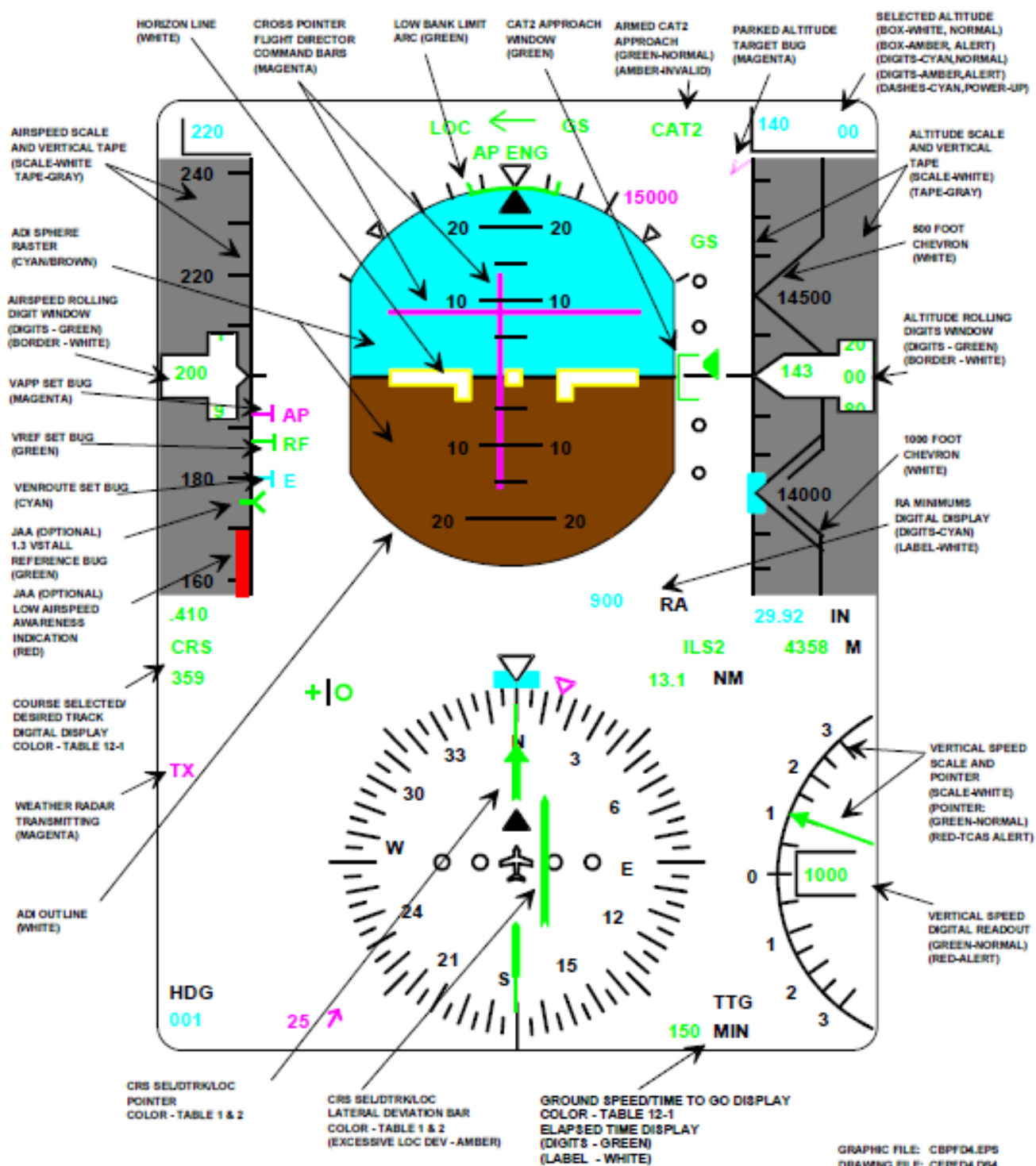


Flap Deployment Speed Awareness

# Cessna Legacy Models 560 Ultra, 560 Encore, 560XL equipped with Honeywell P1000



## Cessna Legacy Models 560 Ultra, 560 Encore, 560XL equipped with Honeywell P1000



Optional Low Airspeed Awareness Display for JAA registered aircraft

AFCAS flight envelope protection consists of:

- Minimum speed protection i.e. speeds below  $V_{MA}$ , the minimum allowable flight speed.
- Maximum speed protection i.e. exceeding  $V_{MO}/M_{MO}$ ,  $V_{LE}$  or  $V_{FE}$ .
- Excessive vertical speed protection.
- Flight path angle protection.
- Automatic gust correction.
- Altitude alerting.

The FCC's calculate the reference speed for display at the PFD speed scale. The speeds are  $V_{MA}$ ,  $V_{SS}$  (stick shaker),  $V_F$  (flap retraction) and green dot speed ( $V_{FTO}$ , the final take-off climb or max angle climb speed).

**NOTE:** If during flight in PROF conditions occur which activate any of the flight envelope protection features, PROF will disengage automatically. Further system behaviour is as described for the applicable AFCAS mode.

#### MINIMUM SPEED PROTECTION

Minimum speed protection consists of  $V_{MA}$  protection, Alpha (or angle of attack) mode and drift down control.

$V_{MA}$  is displayed as the top of the amber strip at the PFD speed scale after becoming airborne.

$V_{MA}$  depends on weight, flap setting, flight phase and altitude.

During take-off and go-around  $V_{MA}$  is equal to  $1.20 V_S$ . In all other flight phases  $V_{MA}$  is equal to  $1.30 V_S$ .

The transition from  $1.20 V_S$  to  $1.30 V_S$  occurs 20 sec. after LVLCH selection (or selection of another vertical mode) or PROF capture.

To safeguard against a possible situation where  $V_{MA}$  remains at  $1.20 V_S$  during approach and landing, AFCAS contains several safety features which assure automatic transition in case LVLCH is not selected or PROF is not captured. In case of an engine failure during take-off or go-around the transition to  $1.30 V_S$  is postponed until after thrust reduction from TOGA or FLEX thrust to MCT (or another thrust rating).

To provide sufficient margin to the low speed buffet at high altitude,  $V_{MA}$  increases to  $1.45 V_S$  at 15 250 ft and increases linearly to  $1.62 V_S$  at FL 350.

#### $V_{MA}$ Protection

AFCAS does not accept speed selections below  $V_{MA}$  i.e. if the pilot selects a speed below  $V_{MA}$ , the FMP speed window will display this speed but the blue speed select bug ( $V_{SEL}$ ) at the PFD speed scale will equal  $V_{MA}$ .

AFCAS will not guide or control to speeds below  $V_{MA}$  because:

- When speed is controlled by elevator ( $IAS_E$  or  $M_E$  at FMA) AFCAS provides AP control and/or FD pitch commands to prevent deceleration below  $V_{MA}$ .
- When speed is controlled by thrust ( $IAS_T$  or  $M_T$  at FMA) ATS adds thrust to prevent deceleration below  $V_{MA}$ .

**NOTE:** If during manual flight with ATS engaged in LVLCH descent mode (thrust limit LL) the FD pitch commands are not followed, speed control does not exist. If this is not noticed e.g. during visual flight and the speed is allowed to drop below  $1.30 V_S$ , AFCAS will change automatically from LVLCH to V/S mode (speed controlled by thrust) and ATS will subsequently control to the selected speed.

#### Alpha Mode

$V_{MA}$  protection is not always available or adequate. Some conditions where  $V_{MA}$  protection is not available are:

- AP engaged in ALT hold or V/S climb, ATS disengaged and idle thrust.
- Manual flight with FD off and ATS disengaged.
- If during manual flight in LVLCH descent the FD commands are not followed.

In addition  $V_{MA}$  protection may be not adequate in conditions of strong turbulence or during fast decelerations. In all these conditions the Alpha mode (or Alpha floor protection) safeguards against too low speeds.

System behaviour upon Alpha mode activation is as follows:

- ATS engages automatically (provided the AT p/b's at the FAC panel are not off),
- the thrust limit changes to TOGA,
- AFCAS will control the speed to  $V_{MA}$  or the selected speed, whichever is the higher, by adding thrust and decreasing pitch when rated TOGA thrust is not sufficient to accelerate.

**NOTE:** The speed at which the Alpha mode activates increases with increasing load factor.

Alpha mode activation depends on the current AFCAS mode and will occur:

- in TO mode when the speed drops approx. 5 kt below  $1.20 V_S$ ;
- in GA mode when the speed drops below approx.  $1.20 V_S + 5$  kt;
- in ALT hold, V/S, and APPR mode when the speed drops approx. 5 kt below  $1.30 V_S$ ;
- if during manual flight in LVLCH climb the FD commands are not followed and the speed drops below  $1.30 V_S$ .

**NOTE:** AFCAS will generate an AFCAS TARGET alert on MFDS when the speed drops approx. 15 kt below the selected speed.

In addition Alpha mode activation will occur if FPV is selected or during manual flight with FD off and the speed drops approx. 5 kt below  $1.30 V_S$ .

**CAUTION:**

WHEN ATS ENGAGES AS A RESULT OF ALPHA MODE ACTIVATION WITH THE ENGINES SPOOLED DOWN OR IN CASE OF A HIGH DECELERATION RATE, THE SPEED MAY FALL WELL BELOW  $V_{MA}$  BEFORE THE AIRCRAFT STARTS TO ACCELERATE.

THE FORCE OVERRIDE SWITCHES ARE DE-ACTIVATED DURING ALPHA MODE OPERATION AND IF, AT THIS MOMENT, THE PILOT ATTEMPTS TO MANUALLY ADVANCE THE THRUST LEVERS TO SPEED UP ENGINE RESPONSE, HE EXPERIENCES HEAVY OVERRIDE FORCES WHICH MAY GIVE THE IMPRESSION THAT THE THRUST LEVERS ARE BLOCKED. ALTHOUGH NOT RECOMMENDED, ATS CAN BE OVERRIDDEN BY HOLDING THE ATS DISCONNECT BUTTONS DEPRESSED AND SIMULTANEOUSLY ADVANCING THE THRUST LEVERS UNTIL THE SPEED IS ABOVE  $V_{MA}$  AND THE ALPHA MODE IS DE-ACTIVATED.

Drift Down Control

See FLIGHT TECHNIQUES.

**MAXIMUM SPEED PROTECTION**

$V_{MAX}$  is calculated by the FCC's and is displayed at the PFD speed scale as the bottom of the red checker bar.

If the pilot selects a speed in excess of  $V_{MAX}$ , the IAS/M display at the FMP will show this speed but the blue VSEL bug will equal  $V_{MAX}$ . AFCAS will prevent exceeding  $V_{MAX}$  by either thrust or elevator control.

If  $V_{MAX}$  is reached and ATS is not engaged, ATS engages automatically and reduces thrust to prevent exceeding  $V_{MAX}$ .

When climbing in IAS select or IAS hold, automatic transition to Mach select or Mach hold occurs at M.76.

When descending in Mach select or Mach hold automatic transition to IAS select or IAS hold occurs at approx 315 kt IAS.

**EXCESSIVE VERTICAL SPEED PROTECTION**

AFCAS safe guards against too low or too high speeds resulting from excessive vertical speed selection by automatic mode change from V/S to LVLCH as follows:

V/S Climb

If the combination of selected V/S and speed exceeds the aircraft performance ATS will first increase thrust to the maximum EPR for the selected thrust rating.

When this thrust is incapable of maintaining the selected speed and vertical speed, the vertical speed will be maintained at the cost of speed.

When the speed falls approx 15 kt below the selected speed the crew is warned by an AFCAS TARGET alert at MFDS.

If no corrective action is taken the aircraft will further decelerate.

At  $1.30 V_S$  AFCAS reverts automatically from V/S climb to LVLCH climb. The aircraft will accelerate to and maintain the (pre) selected speed or  $V_{MA}$ , whichever is higher and climb to the FMP altitude.

V/S Descent

If a vertical speed is selected which will result in exceeding the selected speed, ATS will reduce thrust until idle is reached.

If the speed increases further to approx 15 kt above the selected speed, AFCAS generates an AFCAS TARGET alert at MFDS.

When no corrective action is taken the aircraft will accelerate further.

At  $V_{MAX}$  AFCAS reverts automatically from the V/S to LVLCH descent.

The aircraft will decelerate to and maintain the (pre)selected speed or  $V_{MAX}$ , whichever is lower and descend to the FMP altitude.

# MRJ design approach on the Low Speed Alert function

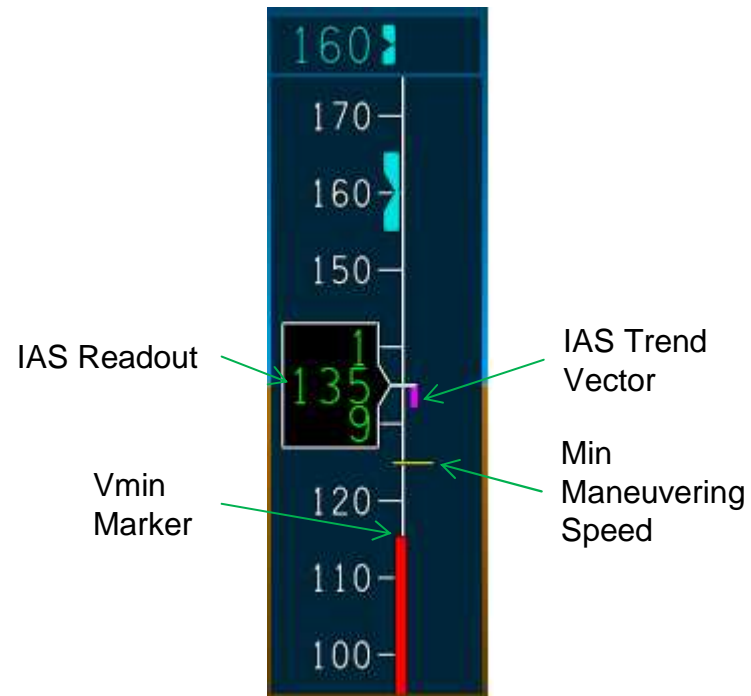
September 30<sup>th</sup>, 2010



# MRJ Low Speed Alert



## Normal Airspeed Tape



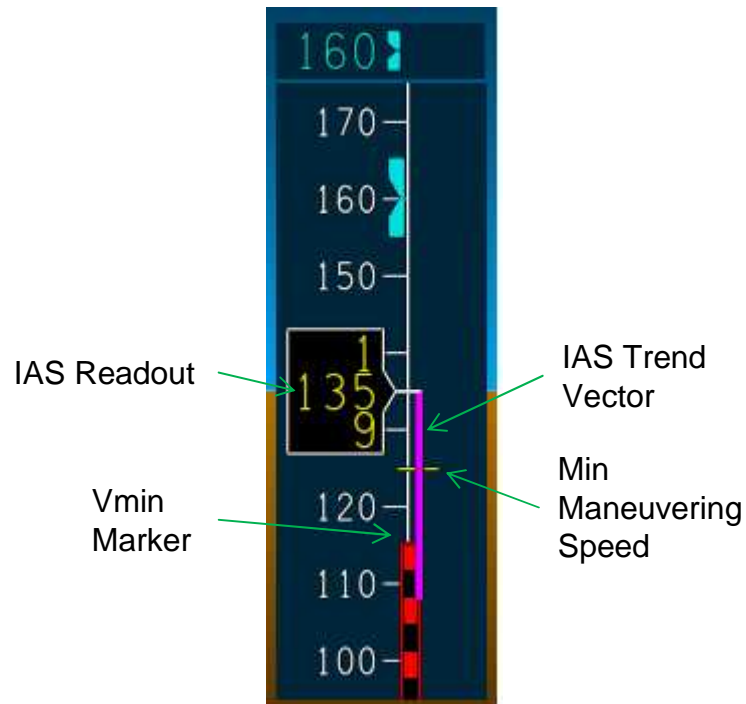
All information contained herein is under development. It is provided for informational purposes only and is subject to change.



# MRJ Low Speed Alert



## Low Speed Caution



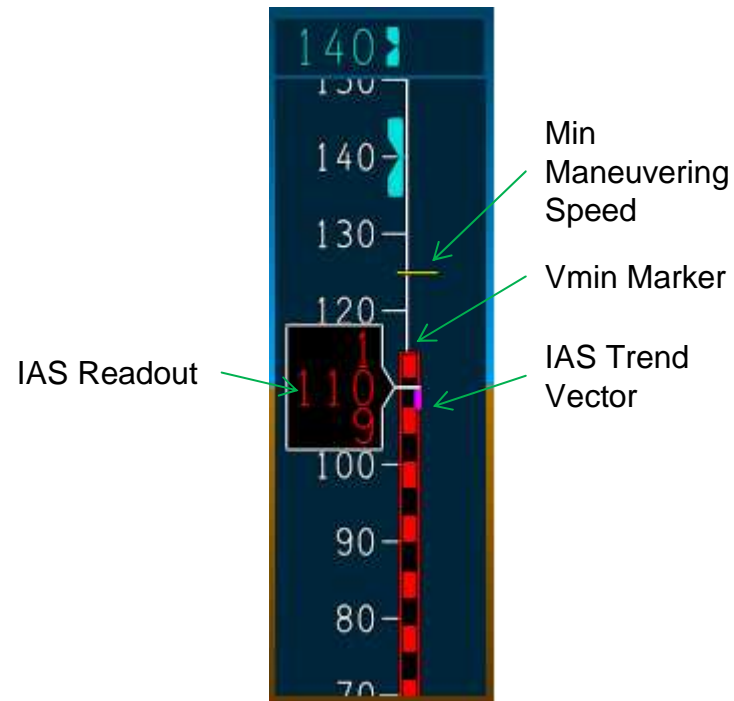
- Vmin is used to depict minimum speed indication. It is an AOA based indication presented on the speed tape that depicts maximum wing lift with FAA mandated safety margins.
- The low speed caution occurs when the IAS trend vector goes below Vmin for 5 seconds or more.
- The airspeed readout changes color (to yellow) when the low airspeed caution is activated
- The low speed Vmin marker will be emphasized

**All information contained herein is under development. It is provided for informational purposes only and is subject to change.**

# MRJ Low Speed Alert



## Low Speed Warning



- The low speed warning occurs when the current IAS is  $<$  the top of the Vmin Marker.
- The airspeed readout changes color (to red) when the low airspeed warning is activated
- The low speed Vmin marker will be emphasized

**All information contained herein is under development. It is provided for informational purposes only and is subject to change.**